

A search for long period variables in Globular Clusters: M22 and IC4499

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Abstract

We report on the results of a long time photometric monitoring of the two metal poor Galactic globular clusters M22 and IC4499 searching for long period variables (LPVs) on the upper giant branch. We detected 22 new LPVs in the field of M22 and confirmed the variability of six known variables. Periods could be determined for 16 of them. In the field of IC4499 we detected and characterized 2 new LPVs. Cluster membership is evaluated for all the variables based on photometry and literature data, and the location of the stars in log P-K diagram is discussed. Our findings give further support to the presence of LPVs at metallicities as low as $[\text{Fe}/\text{H}] = -1.7$. The luminosity range where LPVs are found in metal poor clusters is lower than in more metal rich clusters.

Keywords: stars: AGB – stars: variables – globular clusters: individual (M22) – globular clusters: individual (IC4499)

1 INTRODUCTION

The Asymptotic Giant Branch (AGB) phase is a key stage in the stellar evolution of low and intermediate mass stars. It is characterized by nucleosynthesis, mixing, and mass loss events, and it is therefore of fundamental importance for the cosmic matter cycle. The atmospheres of these stars are highly extended – not least due to the levitation of material by stellar radial pulsation – and this presents major challenge for determining the parameters of these objects (Lebzelter et al. 2010). A study of the variability of AGB stars provides another mechanism for determining the parameters of red giant stars, particularly their mass, their cumulative amount of mass loss and possibly gross abundance variations such as a high helium content.

An interesting possibility is to study AGB stars in single stellar populations where metallicity, mass (age), and distance can be determined from other objects in that system. Therefore, two of us (TL and PW) have started a long time photometric monitoring programme of several Galactic and Magellanic Clouds globular clusters to get an extensive repository of AGB stars in these systems and to use the detected sample in each cluster to further investigate the properties of low and intermediate mass stars

during this final evolutionary stage. The results on several of the clusters studied have been published already: NGC 104 (Lebzelter and Wood 2005), NGC 1846 (Lebzelter and Wood 2007), NGC 1978 and NGC 419 (Kamath et al. 2010), and NGC 362 and NGC 2808 (Lebzelter and Wood 2011). Here we present results on two more clusters, namely M22 (NGC 6656) and IC 4499.

M22 ($l=9.9$ deg, $b=-7.6$ deg) is a galactic globular cluster at a distance of ~ 3.1 kpc from the sun and a mean metallicity of $[\text{Fe}/\text{H}] = -1.64$ (Harris 1996). An age estimate of 12.5 Gyr (van den Berg et al. 2013) places it among the bulk of the Galactic globular clusters. An average reddening value of $E(B-V) = 0.38$ has been found with significant variations across the cluster (Kunder et al. 2013). It was noticed quite early (Hesser, Hartwick and McClure 1977) that the colour-magnitude diagram of this cluster shows an unusual colour spread of the giant branch. This triggered a large number of spectroscopic investigations of the cluster giants which indeed found indications for a metallicity spread similar to the case of ω Cen. Early studies measuring metallicities in a few giants only did not come to conclusive results (Cohen 1981; Pilachowski et al. 1982). The investigation by Da Costa et al. (2009) on 55 red giants showed a broad range of

metallicities between $[\text{Fe}/\text{H}] = -1.9$ and $[\text{Fe}/\text{H}] = -1.45$, in agreement with earlier papers by Lehnert et al. (1991) or Norris and Freeman (1983). The metallicity spread was later confirmed by Alves-Brito et al. (2012). The works of Marino and collaborators (Marino et al. 2009; Marino et al. 2011) gave a strong indication for the existence of two populations with a separation in $[\text{Fe}/\text{H}]$ of 0.15 dex. The two groups differ also in their abundances of s-process elements, the more metal rich ones showing a higher abundance of s-process dominated species. This is in agreement with an evolutionary scenario of the cluster where a second generation of stars is enriched in neutron capture elements by AGB stars (Marino et al. 2011). The split was also found in a sample of M22 subgiants (Marino et al. 2012). While the presence of two populations in M22 or at least a metallicity spread is now widely accepted in the literature, we note that there are also a few papers finding contradicting results, i.e. the existence of only one population (Anthony-Twarog et al. 1995; Monaco et al. 2004; Ivans et al. 2004).

Clement et al. (2001) list 72¹ variable stars known to date in the cluster field. Most of them are RR Lyr stars, but 12 are probably red long-period variables, for some of which periods are given. V5, V8, and V9 are marked as cluster members, while for the others the membership is not clear. Recent surveys for variable stars in that cluster include the study by Kaluzny and Thompson (2001) identifying several SX Phe stars and candidate eclipsing binaries. Eight additional variables were identified in the cluster halo by Kravtsov et al. (Kravtsov et al. 1994).

While M22 belongs to the most massive globular clusters, a further target of our survey, IC4499, is a sparse cluster of rather low density in the outer halo of the Galaxy. We combine here our results of this cluster with the ones for M22 since both clusters have a similar low mean metallicity. Harris (1996) gives its distance from the sun as 17.6 kpc, while Piotto et al. (2002) estimate a reddening value $E(B - V) = 0.23$. These values for distance and reddening are in good agreement with results from RR Lyr variables (Storm 2004). Only a few spectroscopic metallicity determinations are available – see Hankey and Cole (2011) for a recent summary. Values for $[\text{Fe}/\text{H}]$ range between -1.5 and -1.65 (Smith and Perkin 1982; Walker and Nemec 1996) on the Zinn & West (1984) scale. There exists also a number of photometric attempts to determine the cluster metallicity which give somewhat lower values around $[\text{Fe}/\text{H}] = -1.75$ (Fusi Pecci et al. 1995; Ferraro et al. 1995). Hankey and Cole themselves present an extensive spectroscopic study of 43 red giants finding a metallicity of $[\text{Fe}/\text{H}] = -1.52 \pm 0.12$.

There is some debate that IC4499 may be 2-4 Gyr younger than the bulk of the metal poor globular clusters (Ferraro et al. 1995; Salaris and Weiss 2002; Walker et al. 2011). IC 4499 is famous for its high number of RR Lyr stars (Sarajedini 1993; Clement et al. 2001; Walker and Nemec 1996). However, no long period variables (LPVs) are known in this cluster according to Clement et al. (2001).

2 DATA ANALYSIS

The two clusters are part of our observing program to identify and characterize LPVs in Galactic globular clusters. The observations of M22 and IC 4499 were obtained and analysed the same way as the previous papers in this series (see Section 1). Thus we will give here only a brief summary and refer to Lebzelter and Wood (2005) for details. Our monitoring program of IC4499 and M22 started in May 2002 at the 50 inch telescope at Mount Stromlo. This telescope was equipped with a two channel camera used earlier for the MACHO experiment (Alcock et al. 1993). Observations were obtained once to twice a week, but ended unexpectedly after a few months when Mount Stromlo observatory was destroyed by a bush fire. Altogether we collected 21 usable frames for M22 and 27 usable frames for IC4499 over this time span. All observations were done in queue observing mode.

Data from both the blue and the red channel were used for the detection of variables and the determination of light curves. Due to the larger light amplitude of long period variables in the blue than in the red, the blue frames received a higher weight for the detection of variables and the determination of periods. Since the two channels had the same exposure time and since LPVs are typically the brightest stars in the red in an old stellar cluster, several of our variables were over-exposed on the red frames and thus only the blue channel data were useable. Small positional shifts of the cluster on the frame between the observing nights and the presence of an area of bad pixels on the detectors prevented the measurement of all the stars on all our frames.

Variable star detection and extraction of the light curve data was done with the help of the image subtraction code ISIS 2.1 developed by Alard (2000). Stellar fluxes on the reference frames were measured using standard IRAF software. Two images observed in the same night give a differential photometric accuracy for a bright cluster giant around 0.005 mag in the blue. To determine the photometric zero point in V , we identified several stars with known V photometry from the survey by Monaco et al. (2004) on the blue frames. No correction has been applied for the difference between Johnson V and MACHO blue. Since the comparison stars were of colour similar to most of our target stars,

¹Including the 2009 update published on their webpage: <http://www.astro.utoronto.ca/~cclement/cat/C1833m239>.

we expect a rather small difference of around 0.1 magnitudes (Bessell and Germany 1999). To calibrate the red MACHO frames, *R* band magnitudes would have been required. Since these were not available in our case, the red frames were analysed with an arbitrary zero point.

Among the variable stars detected, we selected the long period variables based on the brightness (on the upper giant branch), timescale of the variation (more than 30 days), and a total light amplitude in *V* of at least 0.03 mag. As in the previous papers of this series, Period98 (Sperl 1998) was used to derive periods from our light curves. Period98 is a code which can compute a discrete Fourier transformation in combination with a least-squares fitting of multiple frequencies on the data. A maximum of two periods was considered for each star. For the period range studied here (a few ten days) we do not expect a significant aliasing problem from our sampling of the light curves. Note that, given that the periods of semiregular variables may change from time to time, our results only describe the light variation at the time of observation. This may represent only a small part of a more complex light change. In particular, long time variations on time scales of a year or more are not accessible with our data set.

3 RESULTS

3.1 M22

Five known and eleven new LPVs were found in M22. All stars are identified in Table 1, where coordinates, *V*, DENIS *I*, and 2MASS magnitudes, periods and amplitudes are listed. As in Lebzelter & Wood (2005) we used the variable star identifiers given by Clement et al. (2001) where available. All other variables were named SLW with some number. Uncertain periods or amplitudes are marked by a colon. The previously reported LPV candidates V8, V17, V26, V28, and V31 to V33 were outside our studied field of view.

Three of the previously known LPVs in Table 1 have periods listed in the literature which is given in the last column of Table 1. In the case of V14 – originally detected by Bailey (1902) – we used the literature period of 202 days, since the length of our time series is not sufficient to cover one complete light cycle. We can confirm that the literature period is in a good agreement with our data in this case. For the other two stars with periods from the literature, however, we find quite different periods. In the case of V5 we note some irregular behaviour at the beginning of our light curve, but the second half clearly supports a period of 54 d, i.e. roughly half the literature value. On the other hand, Wehlau and Sawyer-Hogg (1977) found a 93 day period to be the most prominent one over a very long time interval. This star appears to show multiple periods.

For V30 the longer period found in the literature seems to be unlikely, although the situation is not as clear as for V5. A reason for the differences in period with former studies for these three stars is unknown. The period might indeed have changed, but it may also be that the time sampling on which the literature values are based was not sufficient since in all cases we get shorter periods. We note that there is a star close to our variable SLW9 that has been reported variable by Kaluzny and Thompson (2001). It is not clear if their star pk6 is different from SLW9. However, Kaluzny and Thompson classified it as an eclipsing binary. We find no obvious indications for binarity in our data, therefore we suppose that Kaluzny and Thompson discovered a different variable.

We further note that the star V9 in this cluster has been previously identified as red variable. Despite the star having colour and brightness similar to other long period variables in our sample, its variability amplitude in *V* in our data is very small and the star does not show any characteristics of a long period light change. The period value given in the literature could not be confirmed by our data, although the Wehlau and Sawyer-Hogg (1977) measurements seem to support the variability of this star. We suspect that V9 is currently in a phase of quiescence occasionally found in semiregular variables, and the Wehlau and Sawyer-Hogg data indeed show indications for a variable amplitude.

The light variations of the LPVs in M22 are presented in Figure 1 plotted against time starting with the first date of our time series. They are compared with synthetic light curves based on the period given in Table 1. Photometry data are given in Table 4. SLW10 shows a very long period variation in addition to the 46 d period. Such long periods are a well known phenomenon in red variables (Percy et al. 2003; Kiss et al. 1999), but its nature is not understood yet (Wood et al. 2004). For illustrative purposes, a long time trend has been added also to the synthetic light curve. SLW10 is also interesting since it is possibly identical with an X-ray source.

It is quite obvious that most stars show some kind of irregular behaviour on top of the adopted periodic light change as expected for semiregular variables. We note that the period of SLW9, although it seems to give a nice fit is classified as uncertain since we could not detect a second maximum. The light curve of V34 is very unusual for an LPV. Plotted against phase it rather resembles the one expected for an eclipsing binary. We therefore suspect that for this star the observed variability is caused by a companion.

In addition to the variables for which we could estimate a period, we list in Table 2 several red stars that show variability but without a clear periodicity. This may be due to a truly irregular nature of their light change or a larger photometric error, e.g. if there is an

Table 1 Long period variables in the field of M22

Name	RA(2000)	Dec(2000)	V_{mean} [mag]	I^a [mag]	J [mag]	H [mag]	K [mag]	Period [d]	ΔV [mag]	Remark
V5	18 36 10.57	-23 55 00.5	11.16	9.18	7.72	6.99	6.731	54	0.8	P_{lit} 93 d
V14	18 36 40.52	-23 46 07.4	14.84	10.96	8.924	8.037	7.515	202 ^c	2.2	V1266 Cyg, P_{lit} 202 d likely non-member
V30	18 36 41.05	-23 58 19.5	11.34	9.19	7.75	6.991	6.759	62	0.2	P_{lit} 82.5 d
V34 ^b	18 36 26.07	-23 55 33.9	12.41	9.48	8.019	7.225	6.988	63:	0.2:	no P_{lit}
V35	18 36 24.04	-23 54 29.3	12.03	9.41	7.948	7.171	6.949	56:	1.0	no P_{lit}
SLW1	18 35 41.00	-23 53 28.8	12.34	11.06	9.836	9.092	8.896	61	2.2	likely non-member
SLW2	18 35 59.09	-23 51 34.7	13.90	10.77	9.143	8.082	7.816	105	1.2	likely non-member
SLW3	18 35 59.44	-23 54 02.7	15.92	12.72	11.209	10.328	10.06	77:	1.0	likely non-member
SLW4	18 36 17.51	-23 54 26.3	11.41	9.32	7.82	7.011	6.783	57	1.2	
SLW5	18 36 18.38	-23 54 01.3	11.15	9.62	8.289	7.53	7.306	76	0.03	
SLW6	18 36 19.27	-23 53 26.7	11.18	9.53	8.013	7.688	7.257	73:	0.07	
SLW7	18 36 21.01	-23 54 42.5	11.28	9.68	8.407	7.614	7.438	61	0.1	
SLW8	18 36 21.64	-23 55 57.0	11.90	9.36	7.933	7.163	6.929	61:	1.2	
SLW9	18 36 25.42	-23 54 35.6	13.23	11.60	10.512	9.878	9.689	122:	0.6	
SLW10	18 36 26.64	-23 45 02.9	13.71	11.51	9.432	8.498	8.104	46 ^d	0.03	
SLW11	18 36 28.05	-23 53 23.2	11.39	9.55	8.189	7.34	7.197	79	0.07	non-member?

^a I -band data taken from the DENIS database (The DENIS Consortium 2005).^bClassification as LPV doubtful.^cLiterature value used.^dLong secondary period.**Table 2** Long period variable candidates of M22 with unknown periods

Name	RA(2000)	Dec(2000)	V_{mean} [mag]	I^a [mag]	J [mag]	H [mag]	K [mag]
V9 ^b	18 36 08.19	-23 55 02.8	11.06	9.34	7.701	6.926	6.676
SLW12	18 36 02.18	-23 56 50.6	12.35	10.57	9.427	8.755	8.583
SLW13	18 36 10.22	-23 48 44.4	11.94	9.35	7.842	7.005	6.737
SLW14	18 36 14.57	-23 52 45.4	13.40	12.36	11.37	10.794	10.708
SLW15	18 36 20.64	-23 51 36.0	12.89	10.01	8.822	8.072	7.868
SLW16	18 36 23.47	-23 54 53.8	11.23	9.40	7.988	7.23	6.971
SLW17	18 36 26.13	-23 54 51.0	11.32	10.04	8.752	8.013	7.881
SLW18	18 36 26.25	-23 52 32.0	12.79	11.26	10.161	9.491	9.352
SLW19	18 36 26.27	-23 51 48.3	12.62	10.82	9.782	9.136	9.011
SLW20	18 36 30.53	-23 53 57.8	11.59	9.92	8.697	8.007	7.827
SLW21	18 36 33.01	-23 54 35.6	11.28	10.09	9.114	8.589	8.401
SLW22	18 36 33.01	-23 42 44.1	14.15		8.719	7.817	7.469

^a I -band data taken from the DENIS database (The DENIS Consortium 2005).^b P_{lit} 87.7 d.**Table 3** Long period variables of IC 4499

Name	RA(2000)	Dec(2000)	V_{mean} [mag]	I^a [mag]	J [mag]	H [mag]	K [mag]	Period [d]	ΔV [mag]
SLW1	15 00 22.74	-82 12 35.9	12.19	11.19	10.203	9.587	9.424	67	0.8
SLW2	15 01 20.37	-82 12 43.5	13.44	11.71	10.805	10.183	10.027	35	0.8

^a I -band data taken from the DENIS database (The DENIS Consortium 2005).

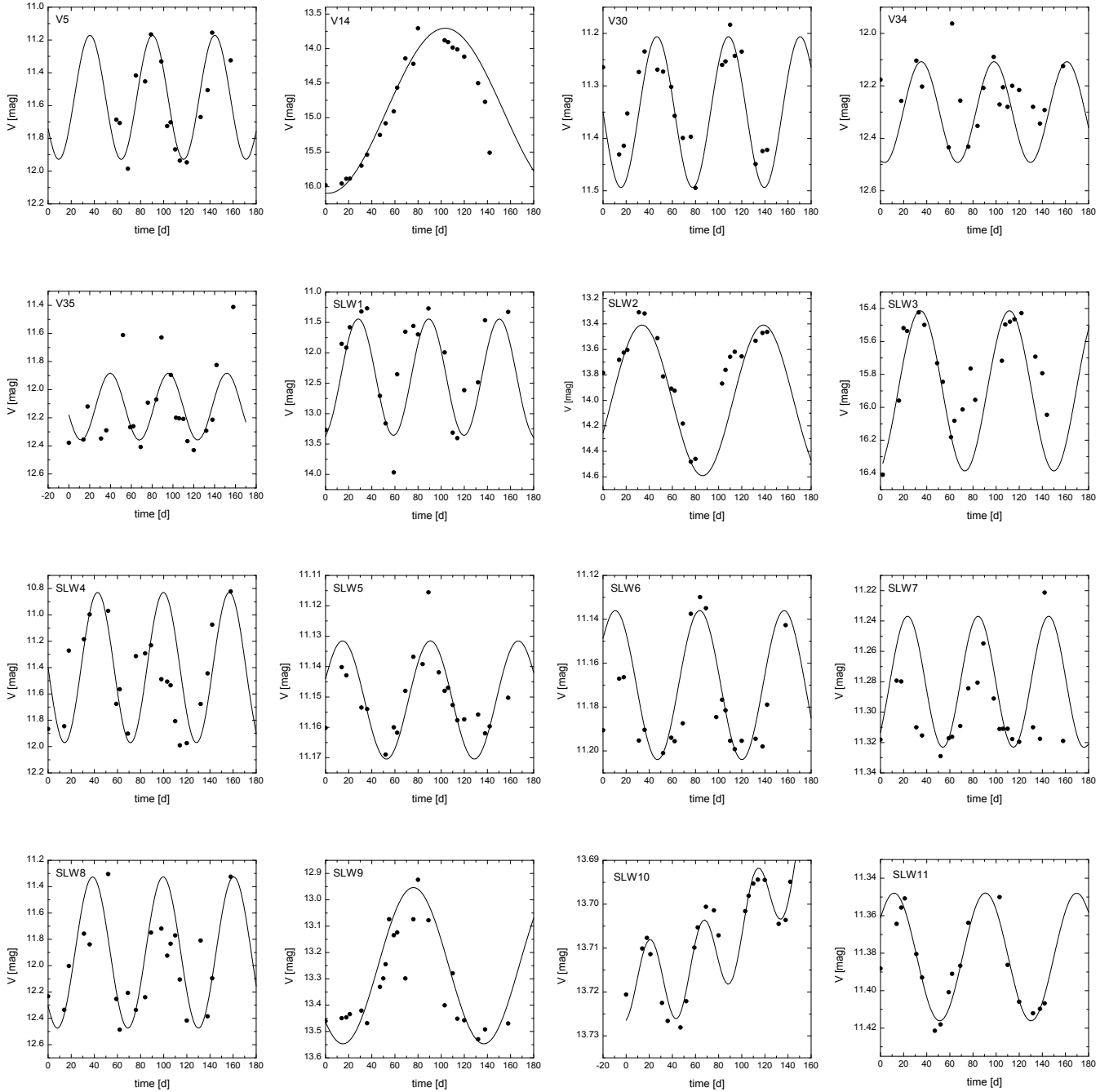


Figure 1. Light change of the long period variables in M22 plotted against time. Starting date is JD 2452420.

other star nearby. We did not investigate these cases further.

A proper motion study for individual stars in NGC 6656 can be found in the paper by Zloczewski et al. (2012). According to these authors, V9, V34, and SLW6 are likely cluster members, V30, SLW11, and SLW20 are probably non-members. However, V30 is listed as a member based on its radial velocity measured by Peterson and Cudworth (1994). These authors find a

mean radial velocity of approximately 147.6 ± 9.8 km/s for a sample of 170 objects they consider cluster members. Their list gives also support to the cluster membership of V5, V9, and SLW4. We note that the LPV candidate V8 listed by Clement et al. (2001), which was not observed within our program, fulfills both membership criteria as well.

From the 2MASS *J* and *K* photometry, we find that V5, V9, V30, V34, V35, SLW1, SLW4, SLW5, SLW7,

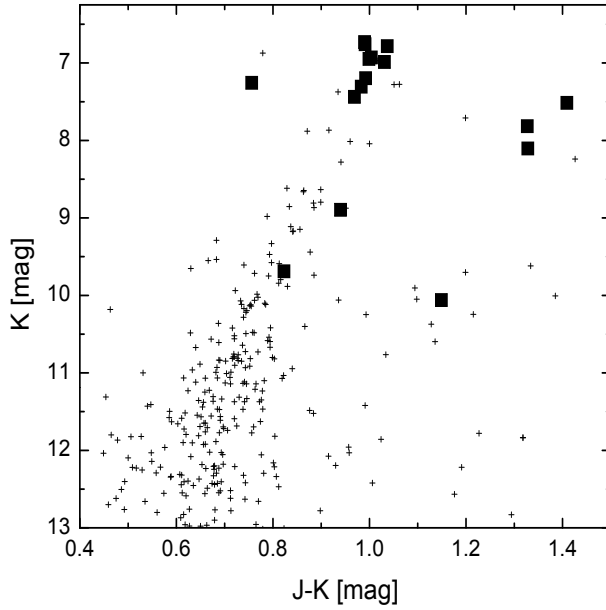


Figure 2. Colour-magnitude diagram of the central part of M22 using 2MASS J and K photometry. The filled boxes mark the variables from Table 1.

SLW8, SLW9, and SLW11 are located on the cluster’s giant branch (see Fig. 2). SLW1 and SLW9 are more than 2 magnitudes below the tip of the giant branch and are thus likely RGB stars. It is unlikely that stars with their relatively large amplitudes would be found this far below the RGB tip, so they are likely to be non-members. SLW6 is offset to the blue in $(J - K)$, but its $(V - I)$ colour is similar to the other red giants. Since it is probably a cluster member due to its proper motion (Zloczewski et al. 2012), we suspect that the 2MASS K brightness of this star may be incorrect. V14, SLW2, SLW3, and SLW10 are found on the right side of the giant branch. It is difficult to decide on their cluster membership since their colour and brightness may be affected by circumstellar dust or their variability (in particular for the large amplitude variable V14). However, they may also be background sources.

3.2 IC4499

In the MACHO data of the second cluster, two objects were found to have significant variability, both previously unreported. They are listed in Table 3 and their light curves plotted against time are presented in Figure 3. Photometry data for both stars can be found in Table 5. No long secondary period has been found in any one of them, both of them are monoperoiodic.

No proper motion data have been reported in literature for IC4499. Hankey and Cole (2011) published a radial velocity study of stars in that field, but none of

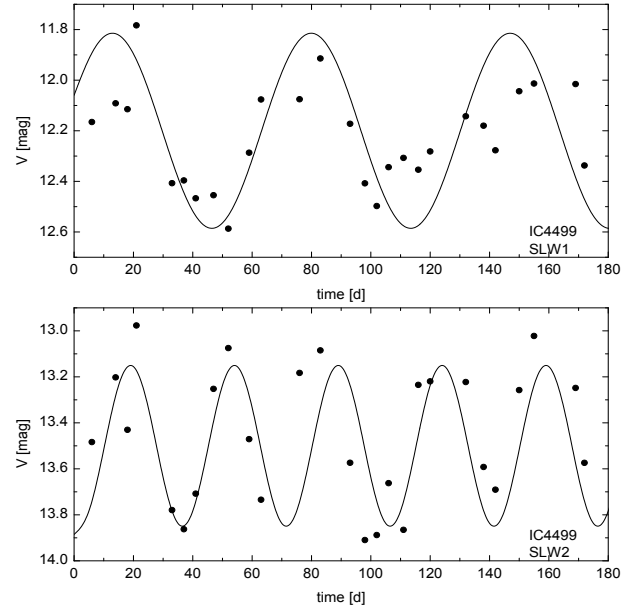


Figure 3. Light change of the two newly detected variables in IC 4499 plotted against time. Starting date is JD 2452420.

our LPV candidates was observed. From their K brightness, both variables are found at the top of the red giant branch, and they are within a 5 arcmin radius of the cluster centre. However, their $J - K$ colour is slightly too blue compared with the bulk of probable RGB stars in IC4499 (Hankey and Cole 2011). SLW1 is also too blue in $V - I$ for an RGB star according to the photometry presented by Walker and Nemec (1996), while SLW2 has an appropriate $V - I$ value. For both stars, their brightness in V places them above the cluster’s giant branch. Their membership is therefore not clear, and a possible coincidence of their location close to the cluster centre has to be counterbalanced with their too blue colour. As Hankey and Cole noted, the cluster is seen through the outer parts of the Galactic bulge, therefore it cannot be excluded that these objects are actually bulge stars. Due to their brightness and colour we tend to classify both objects as non-members.

4 DISCUSSION

For both clusters studied here, the fields observed will likely contain a considerable contribution from field (or bulge) stars. To discuss the long period variables in M22 and IC4499 we thus have to distinguish cluster members and field stars first. As shown above, velocity and proper motion data found in the literature do not allow a clear separation in all cases. We decided to do a first selection of members on the basis of their location in the 2MASS colour-magnitude diagrams (Fig. 2 for M22; see Hankey and Cole (2011) for IC4499). As a next step, we did a

cross-check of these candidates using their pulsational properties.

In Fig. 4 we show a $\log P$ - M_K -diagram for the variables listed in Tabs. 1 and 3 with reliable periods. Absolute magnitudes have been calculated using a distance modulus of 12.46 and 16.23 for M22 and IC4499, respectively. Reddening values $E(B-V)$ of 0.38 and 0.23 have been used. Interstellar extinction in K has been calculated using the relation given in Cardelli et al. (1989). We also added the $\log P$ - K -relations for the LMC given by Ita et al. (2004) shifted with a distance modulus of 18.5 and transformed from the LCO to the 2MASS system following Carpenter (2001). Variables with uncertain cluster membership are marked by open symbols.

Based on the $\log P$ - K -diagram shown in Fig. 4 we further exclude SLW1², SLW2 and the large amplitude variable V14. Since the period is also used as a selection criterion now, we remove all variables with unknown or uncertain period as well. We note that the period from Wehlau and Sawyer-Hogg (1977) would place the star V9 (Table 2) close to the other M22 variables in this diagram. Our resulting sample includes 7 stars, namely V5, V30, SLW4, SLW5, SLW7, SLW10, and SLW11. The membership of SLW11 and V30 is somewhat uncertain according to the literature data, but we decided to leave them in the sample, too. From their brightness, the stars are either on the RGB or on the AGB. In our second cluster, IC4499, the membership of both LPV candidates is doubtful due to their brightness and colour.

Among the clusters studied so far within our monitoring program, M22 and IC4499 are the two with the lowest metallicity. Nevertheless, LPVs are found at least in one of them, M22. Among our 7 good candidates, 4 have V amplitudes of a few tenth of a magnitude or more. We remind the reader that a mira-like variability with a V amplitude of several magnitudes is directly related to the high temperature sensitivity of the TiO bands in the visual part of the spectrum and therefore not expected for low metallicity stars like the ones we study here. This is in agreement with the typical amplitudes found in LPVs in the somewhat more metal rich clusters NGC 362 and NGC 2808 (Lebzelter and Wood 2011). Considering the detection of LPVs in the even more metal poor cluster M15 by McDonald et al. (2010) we propose that this kind of variability appears at the upper end of the giant branch also at much lower metallicity than expected previously (Frogel and Elias 1988).

Beside TiO playing less of a role for the visual amplitude, in low metallicity clusters the long period variables are found at a lower luminosity compared to, e.g., the LPVs in 47 Tuc. This trend seen already in NGC 362 and NGC 2808 is clearly continued in M22 with the most luminous cluster LPV having M_K below -6 , more

than one magnitude below the most luminous LPVs in 47 Tuc. At the same time, the LPV phenomenon sets in at a lower brightness than in 47 Tuc. Should the two variables found in the field of IC4499 be indeed cluster members, this would naturally contradict the findings from the other clusters. It could be explained if this cluster is indeed younger than clusters like M22, but this option has been rejected in the most recent study of this issue by Walker et al. (2011). Therefore, it would be important to clarify their cluster membership or non-membership unambiguously. That we did not find any LPV candidates in IC4499 at a lower luminosity is probably due to the cluster's distance and significantly smaller size in terms of member stars.

Finally, we take a look at the location of the 7 M22 LPVs relative to the LPV $\log P$ - K -relations found for the LMC (Fig. 4). We find four stars close to sequence C, which has been related to fundamental mode pulsation, and three stars between sequence C and C'. The LPV candidate V8 from Clement et al. (2001) would be placed close to sequence C as well using its literature period (61 d) and 2MASS K -magnitude. However, that star is slightly shifted to the blue in $J - K$ relative to the cluster's giant branch, so that its classification as LPV is not totally clear.

Our variables seem to be somewhat offset from the sequences – shifted either to a longer period or a lower brightness. From our previous work (Lebzelter and Wood 2011, in particular) we know that both low metallicity and mass loss tend to shift the $\log P$ - K -relations to the right in such diagrams, in agreement with the very low metallicity of the M22 stars. The alternative explanation would be a small uncertainty in the distance to M22, which seems more unlikely. An interesting feature of the diagram is that the most luminous LPVs in M22 are not found on sequence C but on sequence C'. The low number of variables with reliable data prohibits the drawing of further conclusions on this finding.

To sum up, we report the detection of 24 previously unknown long period variables in the fields of the two metal poor globular clusters M22 and IC 4499. Periods were derived for 17 of the LPVs and cluster membership was discussed. The detection of LPVs as members of these metal poor clusters adds to the sketching of a complete picture of variability on the upper giant branch at various metallicities.

5 ACKNOWLEDGEMENTS

TL acknowledges support by the Austrian Science Fund under project number P23737-N16. The authors wish to thank Warren Hankey for providing radial velocity data for IC4499.

²Not visible in Fig. 4 due to its low K brightness

Table 4 Visual magnitudes of the long period variables in the field of NGC 6656.

Julian Date	V5	V14	V30	V34	V35	SLW1	SLW2	SLW3
	[mag]	[mag]	[mag]	[mag]	[mag]	[mag]	[mag]	[mag]
2452420	11.959	15.980	11.265	12.177	12.378	13.270	13.784	16.410
2452434	12.000	15.957	11.431	12.731	12.356	11.853	13.683	15.960
2452438	11.439	15.887	11.414	12.258	12.120	11.915	13.625	15.519
2452451	11.709	15.886	11.353	12.104	12.349	11.580	13.604	15.537
2452456	11.825	15.698	11.274	12.203	12.289	11.320	13.309	15.424
2452472	11.054	15.538	11.235	11.196	11.612	11.268	13.319	15.499
2452479	11.687	15.253	11.269	12.435	12.267	12.708	13.512	15.732
2452482	11.707	15.084	11.273	11.963	12.261	13.162	13.812	15.846
2452489	11.986	14.911	11.302	12.257	12.409	13.969	13.908	16.182
2452496	11.417	14.567	11.357	12.433	12.093	12.354	13.925	16.082
2452504	11.453	14.142	11.399	12.353	12.071	11.653	14.182	16.014
2452509	11.166	14.221	11.397	12.208	11.629	11.559	14.482	15.765
2452518	11.331	13.708	11.495	12.090	11.896	11.697	14.459	15.955
2452523	11.726	13.880	11.260	12.271	12.200	11.271	13.868	15.717
2452526	11.703	13.906	11.253	12.206	12.205	11.993	13.761	15.497
2452530	11.868	13.985	11.184	12.280	12.209	13.314	13.659	15.480
2452534	11.936	14.012	11.243	12.200	12.367	13.405	13.619	15.465
2452540	11.947	14.117	11.235	12.216	12.432	12.616	13.655	15.428
2452552	11.671	14.503	11.449	12.280	12.293	12.487	13.533	15.693
2452558	11.507	14.773	11.425	12.344	12.214	11.465	13.471	15.794
2452562	11.156	15.509	11.422	12.292	11.825	11.402	13.463	16.046
2452578	11.325	15.537	11.398	12.125	11.412	11.326	13.492	16.326

Julian Date	SLW4	SLW5	SLW6	SLW7	SLW8	SLW9	SLW10	SLW11
	[mag]	[mag]	[mag]	[mag]	[mag]	[mag]	[mag]	[mag]
2452420	11.867	11.160	11.191	11.318	12.234	13.461	13.721	11.388
2452434	11.846	11.140	11.167	11.279	12.336	13.449	13.710	11.364
2452438	11.271	11.143	11.166	11.280	12.003	13.447	13.708	11.356
2452441	11.185	11.153	11.195	11.310	11.757	13.435	13.711	11.351
2452451	10.997	11.154	11.190	11.315	11.839	13.421	13.722	11.380
2452456	10.970	11.169	11.201	11.329	11.305	13.468	13.727	11.393
2452467	11.676	11.160	11.194	11.317	12.254	13.331	13.728	11.421
2452472	11.565	11.162	11.196	11.316	12.487	13.245	13.722	11.418
2452479	11.902	11.148	11.187	11.309	12.207	13.135	13.710	11.401
2452482	11.313	11.137	11.138	11.284	12.337	13.124	13.705	11.391
2452489	11.293	11.139	11.130	11.281	12.240	13.299	13.701	11.387
2452496	11.231	11.116	11.135	11.259	11.749	13.074	13.701	11.364
2452500	11.488	11.142	11.185	11.291	11.719	12.924	13.707	11.323
2452523	11.506	11.148	11.177	11.311	11.925	13.078	13.702	11.350
2452526	11.535	11.147	11.182	11.311	11.833	13.401	13.698	
2452530	11.807	11.153	11.195	11.311	11.770	13.279	13.695	11.386
2452534	11.991	11.158	11.199	11.318	12.106	13.451	13.694	
2452540	11.975	11.157	11.195	11.320	12.418	13.458	13.694	11.406
2452552	11.677	11.156	11.194	11.310	11.810	13.529	13.704	11.412
2452558	11.445	11.162	11.198	11.318	12.385	13.493	13.704	11.410
2452562	11.074	11.160	11.179	11.221	12.096	13.481	13.695	11.407
2452578	10.823	11.150	11.143	11.319	11.325	13.470	13.690	

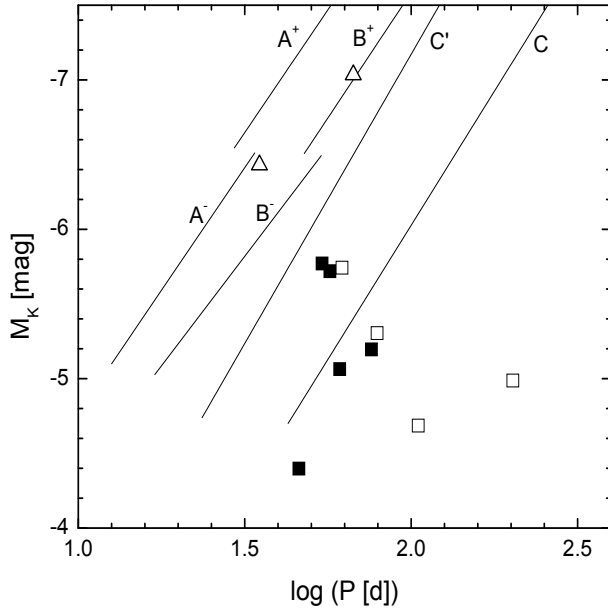


Figure 4. LogP-K-diagram of the variables found in this study. Boxes denote stars in M22 while the two objects in IC4499 are marked with triangles. Open symbols indicate uncertain membership. Only stars with reliable periods based on our data are plotted. Furthermore, the plot gives the location of the logP-K-relations for LPVs derived from the Large Magellanic Cloud by Ita et al. (2004).

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Table 5 Visual magnitudes of the long period variables of IC 4499.

Julian Date	SLW1 [mag]	SLW2 [mag]
2452426	12.165	13.484
2452434	12.091	13.202
2452438	12.115	13.430
2452441	11.783	12.976
2452453	12.407	13.779
2452457	12.396	13.863
2452461	12.467	13.708
2452467	12.455	13.252
2452472	12.587	13.075
2452479	12.287	13.471
2452483	12.076	13.734
2452496	12.075	13.183
2452503	11.914	13.085
2452513	12.172	13.574
2452518	12.408	13.909
2452522	12.498	13.888
2452526	12.344	13.662
2452531	12.307	13.865
2452536	12.354	13.235
2452540	12.282	13.220
2452552	12.143	13.223
2452558	12.180	13.592
2452562	12.277	13.690
2452570	12.044	13.258
2452575	12.013	13.022
2452589	12.015	13.242
2452592	12.337	13.574

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